AN ANALYSIS AND DISCUSSION OF THE CONDITIONS LEADING TO THE SELECTION OF EQUIPMENT FOR AN INTERURBAN ELECTRIC RAILWAY

BY

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

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IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF Bachelor of Science in Railway Electrical Engineering

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P U R P O S E .

The purpose of this thesis has been the selection of equipment for an interurban road. The profile considered is the Danville, Urbana and Champaign Railway. That part of the road lying between Urbana and the village of St. Joseph was chosen as being typical of the run, and the equipment was selected from performances over this length of the road. Five different possible equipments were considered. Out of these five the equipment which gave the most satisfactory operation was chosen.

I. Introduction.

1. The selection of the proper equipment for use on a proposed electric railway is one of the most importamt problems confronting the engineer in charge. Upon the outcome of this selection will depend in a large measure the eventual success or failure of the new line.to secure and hold its share of public patronage, and hence its success or failure as a business venture.

After the right of way has been secured and the proposed profile plotted, the size and needs of each town and village tributary to the new railroad are carefully ascertained. From this knowledge, and from that obtained by an investigation of the methods of operation of competitive roads, if there be such, a train schedule and time table are made out. The arrangements of trains on this time card is such as, it is thought, will give the most efficient service to the greatest number of people along the right of way, and thereby bring the greatest returns to the investors. Having determined upon the time card and knowing the profile of the proposed road, the next step is to select such a motor equipment as will be able to make the proposed schedule in a satisfactory manner. The most practical method in use at the present time of selecting motor equipment is by means of the speed time curve. After drawing the speed time curve other auxiliary curves can be constructed to the same time base showing the power used, and if desired, the current drawn from the line. These curves afford a means of ascertaining which of a number of equipments will make a certain run in the best time, and will show at the same time the amount of power used by the car.

II. Discussion of Speed-Time Curves.

1. The speed time curve is, as its name indicates, a curve having for its ordinates the varying speeds of the car under consideration plotted against the corresponding times as abscissae. It is readily apparent that the slope of any part of the curve will represent acceleration, since it is measured by the quotient of speed by time, which is acceleration. Curves having a positive slope represent acceleration or increase in velocity. Curves having a negative slope represent retardation or decrease in velocity. Curves having no slope at all, but which run parallel to the abscissa represent uniform speed. Now the product of velocity by time gives distance, hence the area under the speed time curve represents distance travelled. Acceleration is the rate of change of velocity per unit time, while velocity in turn, is the rate of change of distance per unit time. Hence:-

$$v = ds/dt, \quad a = dv/dt = d^2s/dt^2, \qquad (a)$$

where v denotes velocity, a acceleration, ds a small increment of distance, dv a small increment of velocity, and dt a small increment of time. The expression dv/dt will be spoken of in this thesis as "acceleration cofficient".

The following formulae were used in determining the values of "acceleration coefficients" :-

$$F = MA \qquad A = F/M \qquad (b)$$

where F equals force exerted on a body expressed in pounds, M is the mass of moving body in g-pounds, A equals acceleration of body in feet per second per second but $M = w/g$, where w = weight of body in pounds, and g = value of gravity = 32.2

$$\text{hence } A = 32.2F/w \qquad (c)$$

But we wish to express acceleration in miles per hour per second, and weight in tons.

Let a denote acceleration in miles per hour per second and W = weight in tons

$$a = 60x60/5280\ A = .682\ A, \quad w = 2000\ W$$

substituting these values in (c)

$$a = .682x32.2F/2000W = .01098\ F/W \qquad (d)$$

The values of(a)obtained by the above formula will be the desired "acceleration coefficients".

2. The method of procedure was as follows:- From the characteristic curves (furnished by the manufacturer) of the motor under consideration values of tractive effort (F) were found for various speeds. By means of formula (d) values of acceleration coefficient (a) were found corresponding to the several speeds. These values were then plotted as ordinates against the speeds as abscissae, see figure 2

In using formula (d) the value of w used was the weight in tons per motor, namely the weight of car divided by four. Values of car resistance in pounds per ton were obtained for various speeds from the curve shown in figure 12 which was developed by the railway Engineering Department of the University of Illinois for a 30 ton car. From these values of car resistance the equivalent acceleration coefficients were found by means of formula (d) and plotted below. The ordinates of this curve were then subtracted from those of the curve b and the curve c.

of net acceleration plotted, leaving as its ordinates the difference between ordinates of curves b and a

Lines were laid off parallel to and below the abscissa whose ordinates equal the acceleration coefficients due to up grades of different degrees of steepness. Corresponding lines were laid off above the abscissa.representing the negative acceleration due to down grades. By means of these last named lines it is easy to find the acceleration for any grade by subtracting or adding (according to the sign of the grade) the proper amount from the ordinates of curve

As an additional aid in plotting the speed time curves a chart of reciprocals was drawn up, see figure 1. Seven different curves were drawn up for increments of speed of 10, 5, 2.5, 1, .5,.25, and .1 miles per hour.

The ordinates of these curves represent acceleration coefficients plotted to the same scale as figure 2. The abscissae represent time in seconds.

By aid of these two last named curves ,(1 and 2) curves of acceleration on level track, 1% up, and 1% down grade figure 7 was plotted and from this the main speed time curves were derived by interpolation. The method pursued in using charts 1 and 2 to plot a speed time curve is as follows:-

A uniform acceleration rate of one and one half miles per hour per second was used as long as possible. Of course, after the speed of the car had increased above a certain limit the tractive power of the motors was no longer able to give as high a rate of acceleration, and said rate therefore fell off gradually as the speed increased until the car had attained uniform speed having reached the highest speed on that grade with that equipment.

Starting at zero speed and time a point was made. Then an increment of say ten miles per hour in speed was taken and with the dividers the distance represented by the ordinate under the curve 7 at 10 miles per hour was taken off. The dividers were then run along curve fig 1which was constructed for a ten mile increment until the distance from the curve to the zero line was equal to that for which the dividers were set. The abscissa marked by this location of the dividers represented the time in seconds taken for the car to reach a speed of ten miles per hour from a speed of zero miles per hour. This located a second point on the curve. Next on an increment of say five miles per hour was taken, making the speed of the point under consideration fifteen miles per hour. The same steps were gone through with as before except that when using the chart of coefficients,the curvewhich is constructed for an increment of speed of five miles per hour is used instead of the one constructed for an increment of ten miles per hour as was before used. Each increment of time is added to the sum of the increments which have been found before it, and this sum total of time is plotted as abscissae against the corresponding speed in miles per hour as ordinates, thus locating further points along the speed time curve. By the above means three acceleration curves were plotted for each of the six motor equipments considered, one for level track, one for 1% up, and one for 1% down grade. A similar set of three curves figure was constructed for drifting with power off and also a set of curves for retardation due to changing from one grade to a higher one. The final speed time curves were plotted by tracing and interpolating from the above named curves. Distances were roughly calculated from distance curves plotted on each of the above named curves, and then checked by means of the planimeter. (It will be remembered here that distances are represented by the area under the speed time curve.)

Since the purpose of this thesis is to afford a comparison of the relative suitability of the five equipments, it was decided not to drift during any part of the run, but to run up as closely as possible to the approaching stop with power on and then brake at the uniform rate of one and one half miles per hour per second. This allows us to obtain a comparison of the relative merits of each of the five equipments by means of the time taken by each to make the run between Urbana and St. Joseph, a distance of 8.56 miles. In plotting the speed time curves the time allowed for stops varied somewhat with different equipments. To eliminate any error due to this fact the total time of stops for each run was subtracted from the total time required for the run. The result is the actual time consumed in making the run irrespective of stops.

Kilowatt Curves.

Kilowatt curves were also plotted, showing the energy consumption at any time. The area under these curves represents the total power consumption. These are plotted from the motor characteristics by finding the current used at a given speed of car. It was assumed in plotting all curves for this thesis that trolley voltage is 500 volts. While this voltage may not hold as the average voltage, yet it does not at all affect the comparative ratio of the results.

III. Description of Road.

1.The division of track used was that part of the Danville, Urbana and Champaign R. R. lying between Urbana and St. Joseph, Ill., a distance of 8.56 miles. The reason for beginning the run on the edge of Urbana was to eliminate the annoyance due to the numerous switches and curves to be found in the Champaign and Urbana yards. The maximum grade encountered along this portion of the road is 1%, the highest degree curve is 20°. All curves were reduced to equivalent grades by use of the factor given by Mallioux in his 'Notes on the plotting of Speed Time Curves p. 1062. This formula is as follows:-

$G = .045\ C$, where G = equivalent grade, i.e. one offering the same train resistance, and C is the degree of curvature. After we had obtained the "net equivalent grades" by combining the grades and curves we found the greatest value to be a plus 1.218% grade. For a complete list of grades and curves see table 13 The profile used was that made by the Department of Railway Engineering.

IV. Schedules Used.

We worked in the immediate vicinity of the present schedules, as they are giving very satisfactory service at the present time. Following are the schedules giving time and distances from Wabash R. R. tracks to the several stops:-

Local Run.

Name of Stop	Distance Miles	Time-minutes.
Wabash Track	0	0
Burneys	.64	1.4
Hunts	1.01	2.2
Roe	2.10	4.7
Hudsonville	3.60	8.1
May View	4.82	11.0
Kirkpatrick	5.93	13.8
McElwee	6.93	16.3
Salt Fork	7.96	19.0
St. Joseph	8.56	22.0

Limited Run.

Wabash Track	0	0
May View	4.82	11
St. Joseph	8.56	17

Motor Equipments Considered.

Following are the motor equipments dealt with in this thesis:

(1) 30 ton car with 4-50 H. P. motors

(2) 30 " " " 4--50 H.P. motors

(3) 30 " " " 4--60 H.P. "

(4) 40 " " " 4--60 H.P. "

(5) 40 " " " 4--75 H.P. "

In referring to the above equipments in the remaining part of this thesis the above figures will be abbreviated. Thus the term 4-50-30 equipment will be used to designate a 30 ton car equipped with a 4-50 horse power motors.

The following table shows the maker's name and the number of his bulletin, giving motor specifications.

Makers Rating	Maker's Name	Style of Motor	Maker's Publication No.	Gear Ratio Used.
50 H.P.(a)	Westinghouse	101-D		22-62
50 H.P.(b)	General Elec.	GE-90-A-2	" 4454-A	19-67
60 H.P.	" "	GE-87	" 4442	23-64
75 H.P.	" "	GE-73-C-11	" 4294	21-54

Results Obtained.

The following tables show the camparative values of the several motor equipments (1) as to time required to make run and (2) as to kilowatt hours consumed.

Local Run.	4-75-40	4-60-40	4-60-30	4-50-30(b)	4-50-30(a)
Time to make run, min.	20.9	23.6	21.6	22.4	19.4
Time spent in stops, min.	1.4	1.35	1.9	0Q95	1.4
Net time of run, min.	19.5	22.25	19.75	21.45	18.00
Total power used, kw. hrs.	29.9	22.75	21.96	19.67	23.38
Average current per motor	46.0	30.70	33.40	27.50	39.00
Rated full load current of motor	130	105	105	88	86
Limited Run.					
Time to make run, min.	17.0	17.6	17.0	18.0	15.8
Time spent in stops, min.	0.22	0.25	0.22	0.3	0.26
Net time of run, min.	16.78	17.35	16.78	17.7	15.54
Total power used kw. hrs.	21.88	16.52	15.82	15.02	16.60
Average current per motor	39.1	28.6	26.2	25.5	32.0

Average time taken on D. U. & C. R. R. to make the same run

Local

Running time	22 min.
Stops	1.5 min.
Net time	20.5 "

Limited

Running time	17.00 min.
Stops	0.25 "
Net time	16.75 "

The train time possible with the several equipments is as follows:-

Limited

May View	9.7	9.5	9.2	9.6	8.5
St. Joseph	17.0	17.6	17.0	18.0	15.8

Local

	4-75-40	4-60-40	4-60-30	4-50-30 (b)	4-50-30 (a)
Wabash R. R.	0	0	0	0	0
Burneys	1.5	1.7	1.4	1.7	1.5
Hunts	2.8	3.1	3.0	3.0	2.8
Roe	5.4	6.0	5.9	5.8	5.3
Hudsonville	8.7	9.4	9.5	9.3	8.2
Mayview	11.5	13.4	12.5	12.3	10.7
Kirkpatrick	14.0	16.1	14.5	14.8	12.9
McElwee	16.4	18.7	17.0	17.3	15.1
Salt Fork	18.8	21.2	19.8	19.8	17.4
St. Joseph	20.9	23.6	21.6	22.4	19.4

The above results were taken direct from the speed time curves plotted. They should not be used for a close comparison of the running times of the several equipments since the total time allowed for stops is not the same in every case. To eliminate this error the table on page 11 was prepared. In this table the total time of stops has been subtracted from the total time of run, giving the net time actually spent in the run.

V. Conclusions.

1. Choice of "Local" Equipment.

It will be seen from the table on page 11 that no great advantage is possessed by any one equipment as to the length of time required to make the run. The difference in power consumption, however, is somewhat more marked, there being a variation of from 19.67 Kw. hours in the case of the 4-50-30 equipment to 29.9 kilowatt hours in the case of the 4-75-40 equipment.

It was decided to select the 4-50-30 (a) equipment for local service. The net time required by this equipment to make the run is only 18 minutes, while the net schedule time is 20.5 minutes. This good showing in speed is the result of the high gear ratio (1.82) on which calculations for this motor were based. As a result the power consumption is a little above the average, being 23.38 kilowatt hours.

The next equipment, the 4-50-30 (b) with a gear ratio of 2.53 has the low power consumption of

19.67 kilowatt hours, but takes 21.45 minutes to make the net run. Since the motors in both of the above named equipments are rated at fifty horse power, the difference in their power consumption and in the speed showing lies in the difference in gear ratios used on the two equipments.

By interpolation between the two values of gear ratio used we find that with a 50 HP motor having a gear ratio of 2.363 we can obtain the schedule speed now maintained on the D. U. & C. R. R. with a power consumption for the run of 20.54 kilowatts. We therefore recommend the 4-50-30 equipment with a gear ratio of about 2.36 for the local run.

2. Discussion of other equipments for local Service

The 4-75-40 equipment is able to make the run in 19.5 minutes net with a power consumption of 29.9 kilowatt hours. Although the gear ratio used is low, being 2.57, we have the highest power consumption of any of the five equipments. This equipment is too large for local service under the conditions which obtain on this road.

The same motors were considered for both the 4-60-30 and the 4-60-40 equipments. The difference in the time schedules and the power used is due solely to the difference in weights of the two cars. This difference is more noticeable on a local run where starts and stops are frequent than on one where the speed is more nearly constant, as would be the case in a limited run.

3. Choice of Limited Equipment.

It might at first thought seem advisable to use the same equipment on both local and limited cars in order to have an interchangeable system. There are no doubt advantages to be derived from the "interchangeable" system, but for the class of service existing on the D. U. & C. R. R. there is seldom enough extra traffic to require the interchange of cars. On the other hand it is desirable to use a heavier car for limited work than is economical for use in local work. The higher speed at which the car is run makes a heavy car a necessity for comfortable travel. Again the heavier car adapts itself to more luxurious furnishings. Both of these results are a necessity for limited service and especially sowhere an extra fare is charged. Owing to the less frequent stops on the "limited" the extra inertia of the heavier car does not make an appreciable difference since the speed is nearly uniform once the car has gotten started.

For the above reasons it was decided to choose a heavier car for the "limited" work. The 4-60-40 equipment was chosen on account of its low power consumption. Allowing for one stop of .25 minute duration this equipment will make the run in 17.6 minutes with a kilowatt hour consumption of 16.52. The average current is only 28.6 amperes per motor although the full load rated current of the motor used is 105 amperes. This equipment requires 17.35 minutes in making the net run with the gear ratio 2.78, while the net run now taken by the limited cars on the D. U. & C. R. R. is 16.75 minutes. In order to make the schedule a gear ratio of 2.68 may be used. This will bring the power consumption up to 17.1 kilowatt hours.

4. Discussion of Other Equipments for Limited Service.

The same gear ratios were assumed in plotting the speed time curves. The same relative showing was made in the limited runs as was made in the local runs.

Plate I

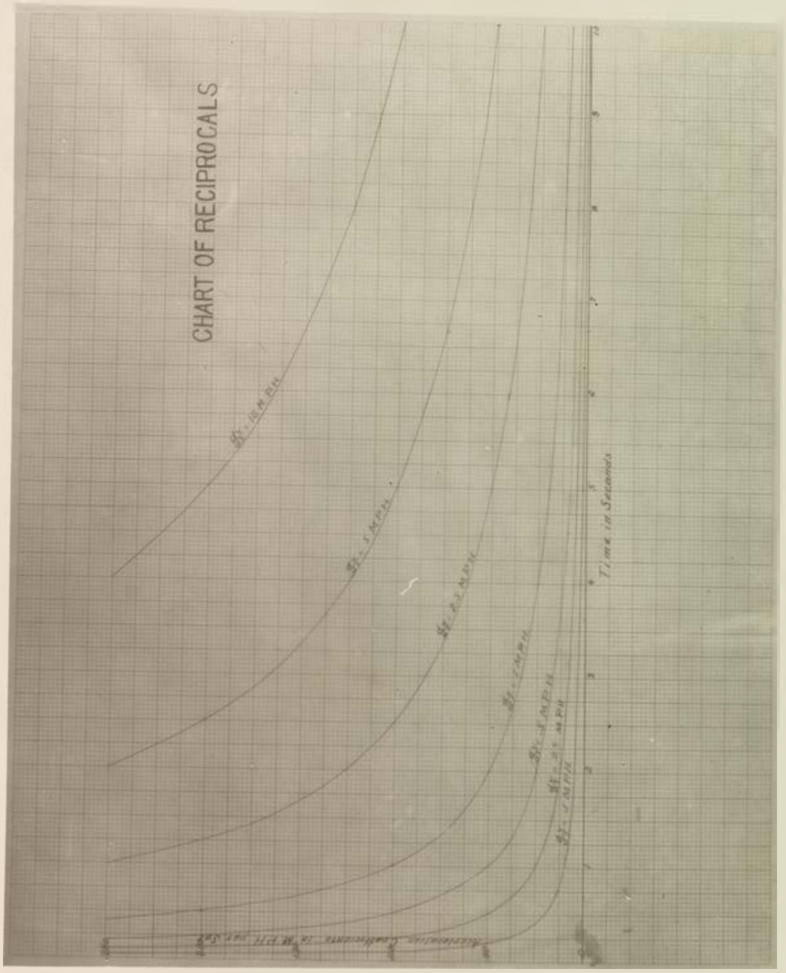


Plate II

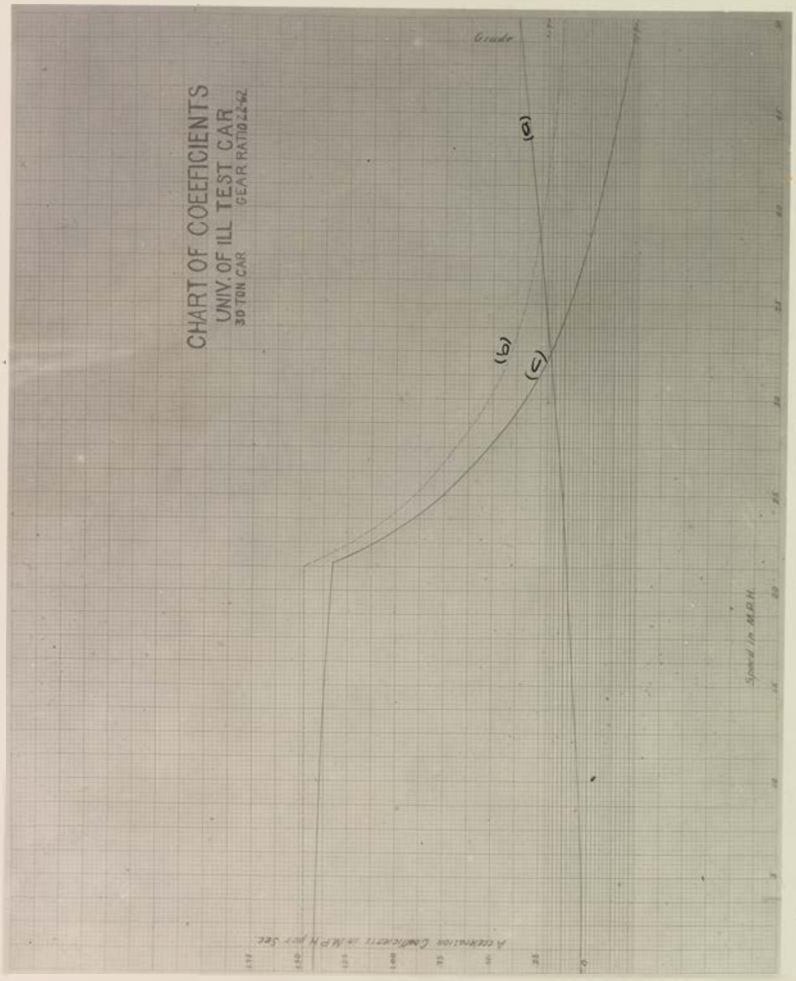


CHART OF COEFFICIENTS
UNIV. OF ILL TEST CAR
30 TON CAR
GEAR RATIO 22-62
Grade
(a)
(b)
(c)
Speed in M.P.H.
Acceleration Coefficients in M.P.H per Sec

Plate III

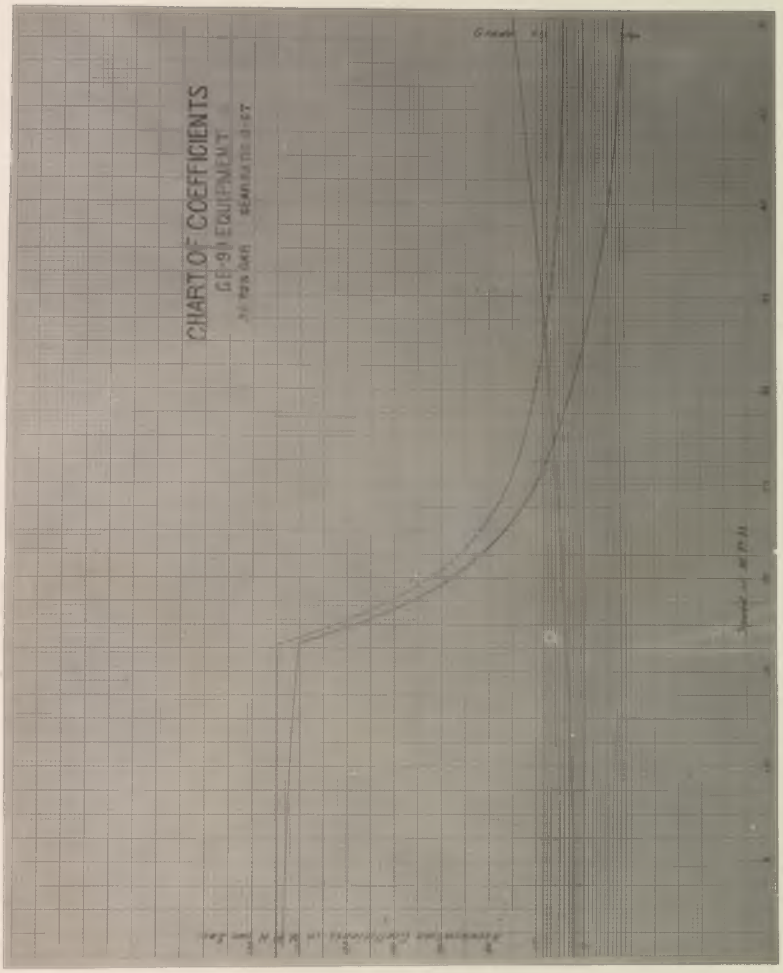


Plate IV

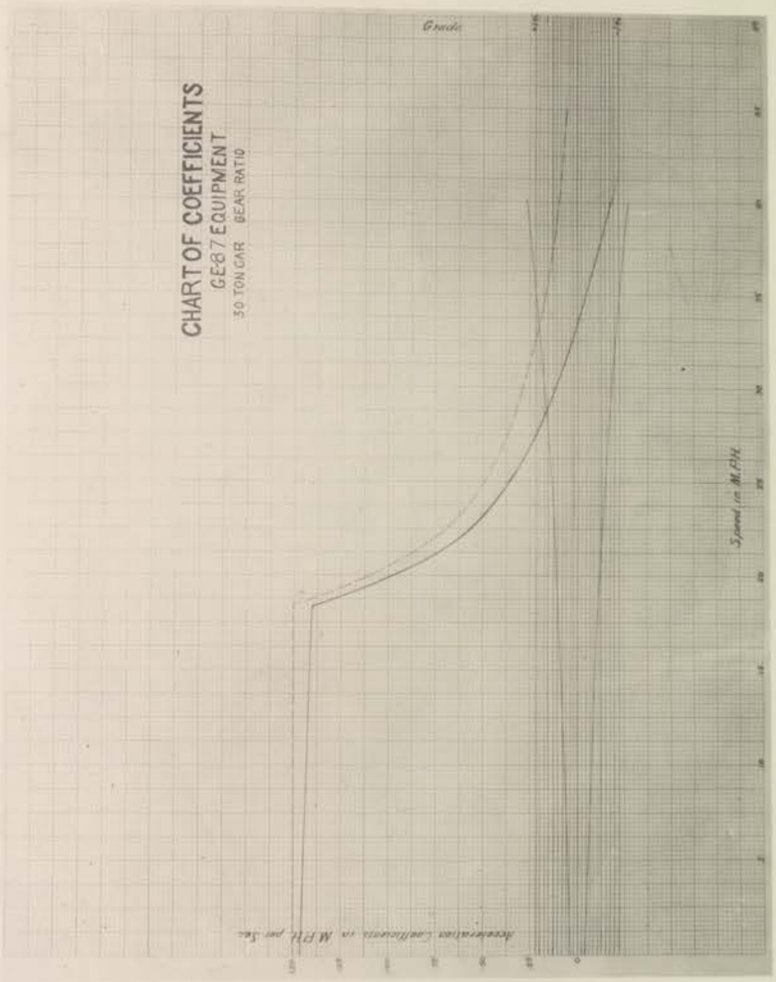


CHART OF COEFFICIENTS
GE-87 EQUIPMENT
30 TON CAR GEAR RATIO
Grade
Speed in M.P.H.
Acceleration Coefficients in M.P.H. per Sec.

Plate V

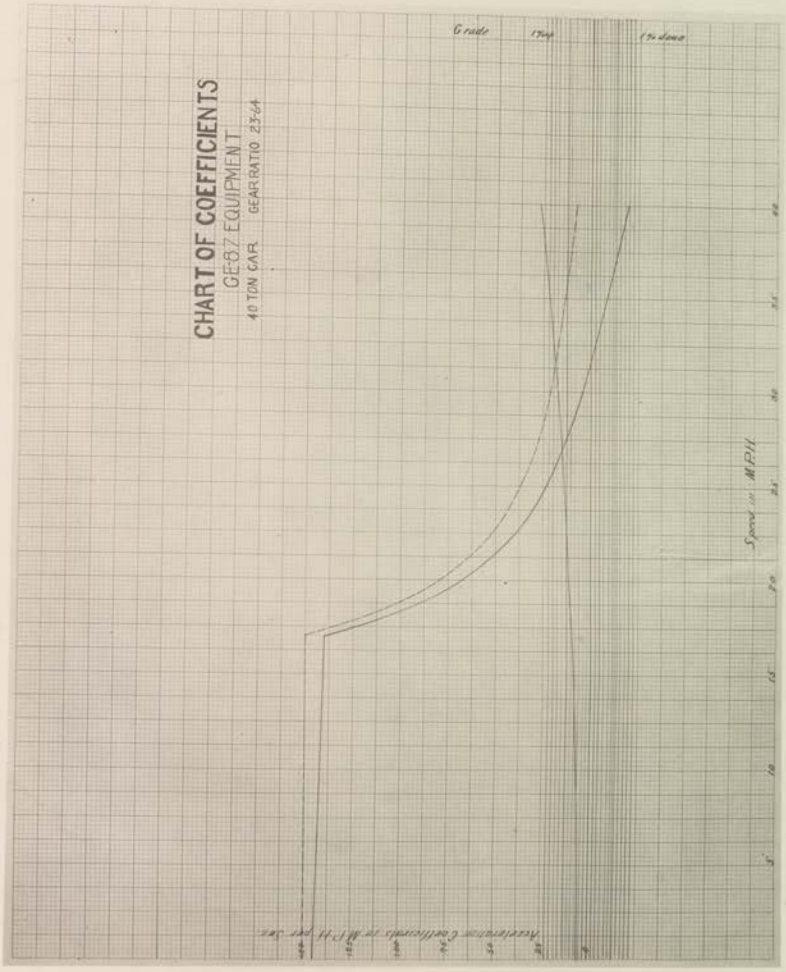


CHART OF COEFFICIENTS
GE-87 EQUIPMENT
40 TON CAR GEAR RATIO 23-64
Grade
1% up
1% down
Speed in M.P.H.
Acceleration Coefficients in M.P.H. per Sec.

Plate VI

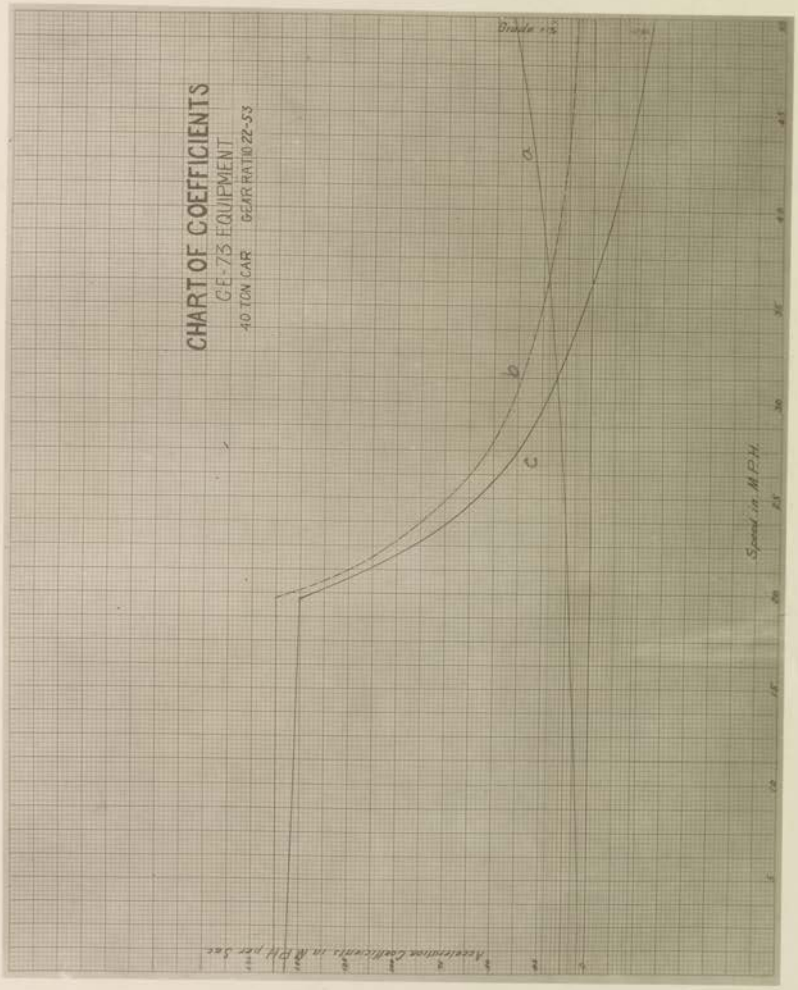
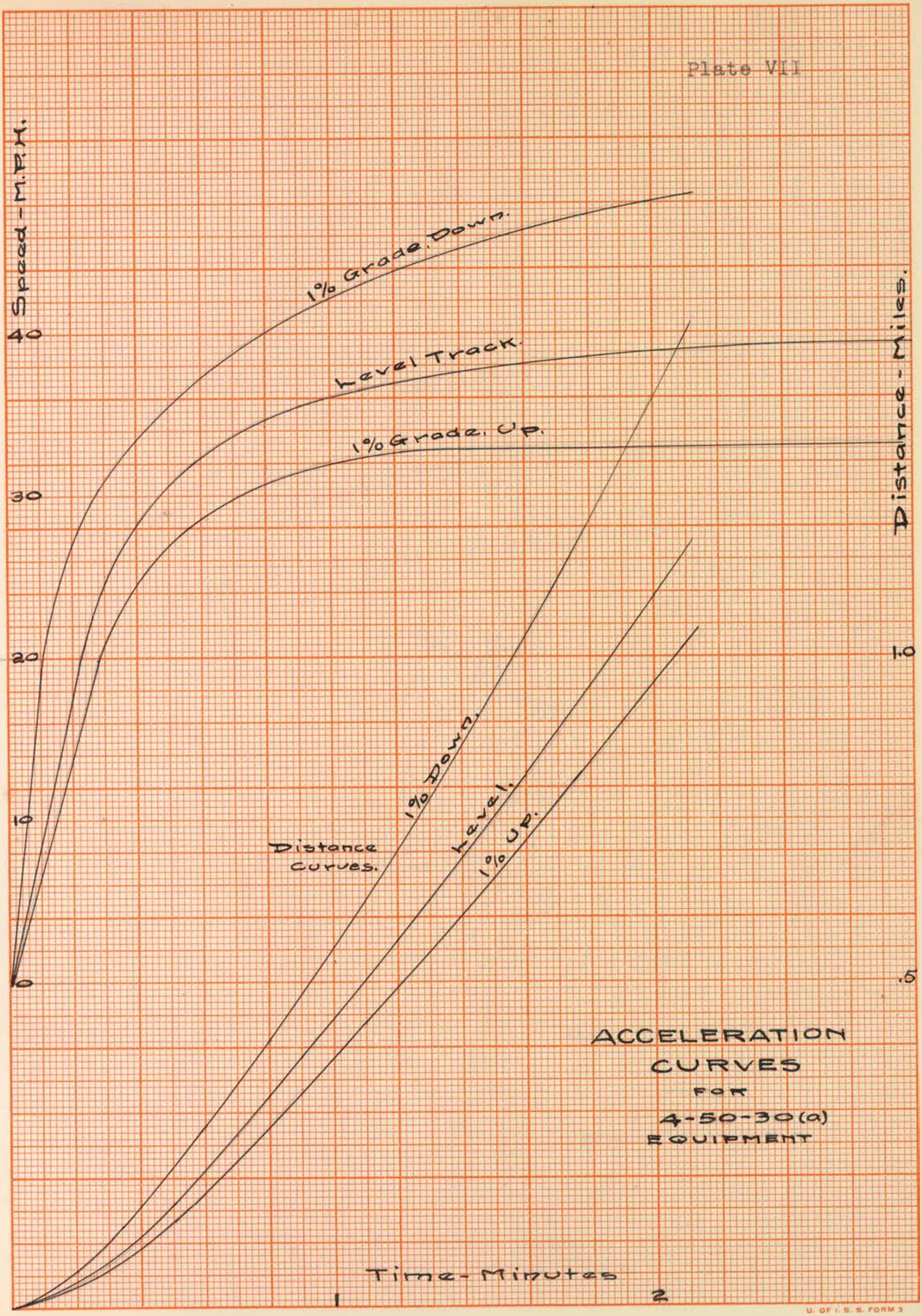


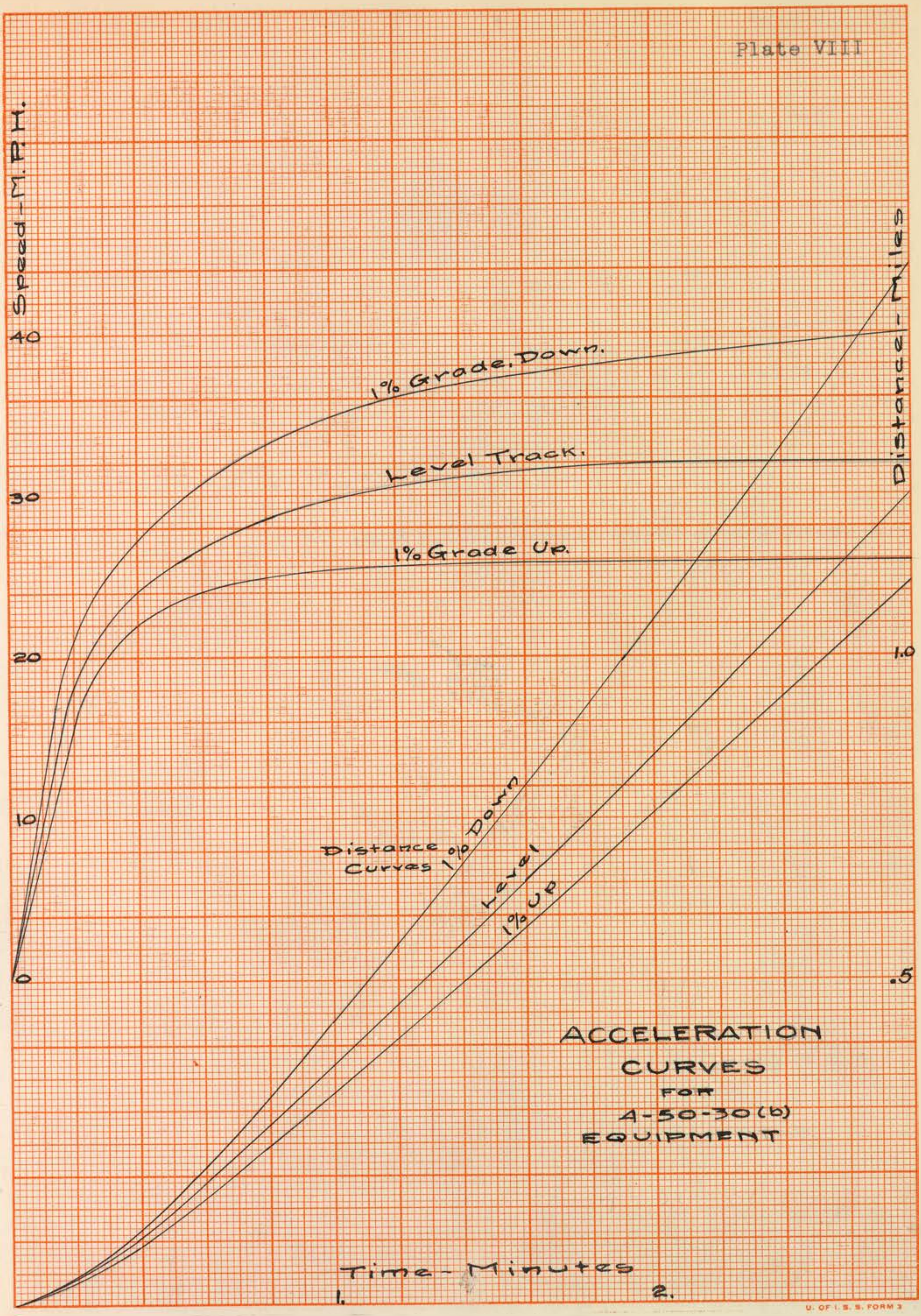
CHART OF COEFFICIENTS
GE-73 EQUIPMENT
40 TON CAR GEAR RATIO 22-53
Speed in M.P.H.

Plate VII



Speed - M.P.H.
Distance - Miles.
1% Grade Down.
Level Track.
1% Grade. Up.
Distance Curves.
1% Down.
Level.
1% Up.
Time - Minutes
0
10
20
30
40
.5
1.0
1
2
ACCELERATION CURVES FOR 4-50-30(a) EQUIPMENT

Plate VIII



U. OF I. S. S. FORM 3

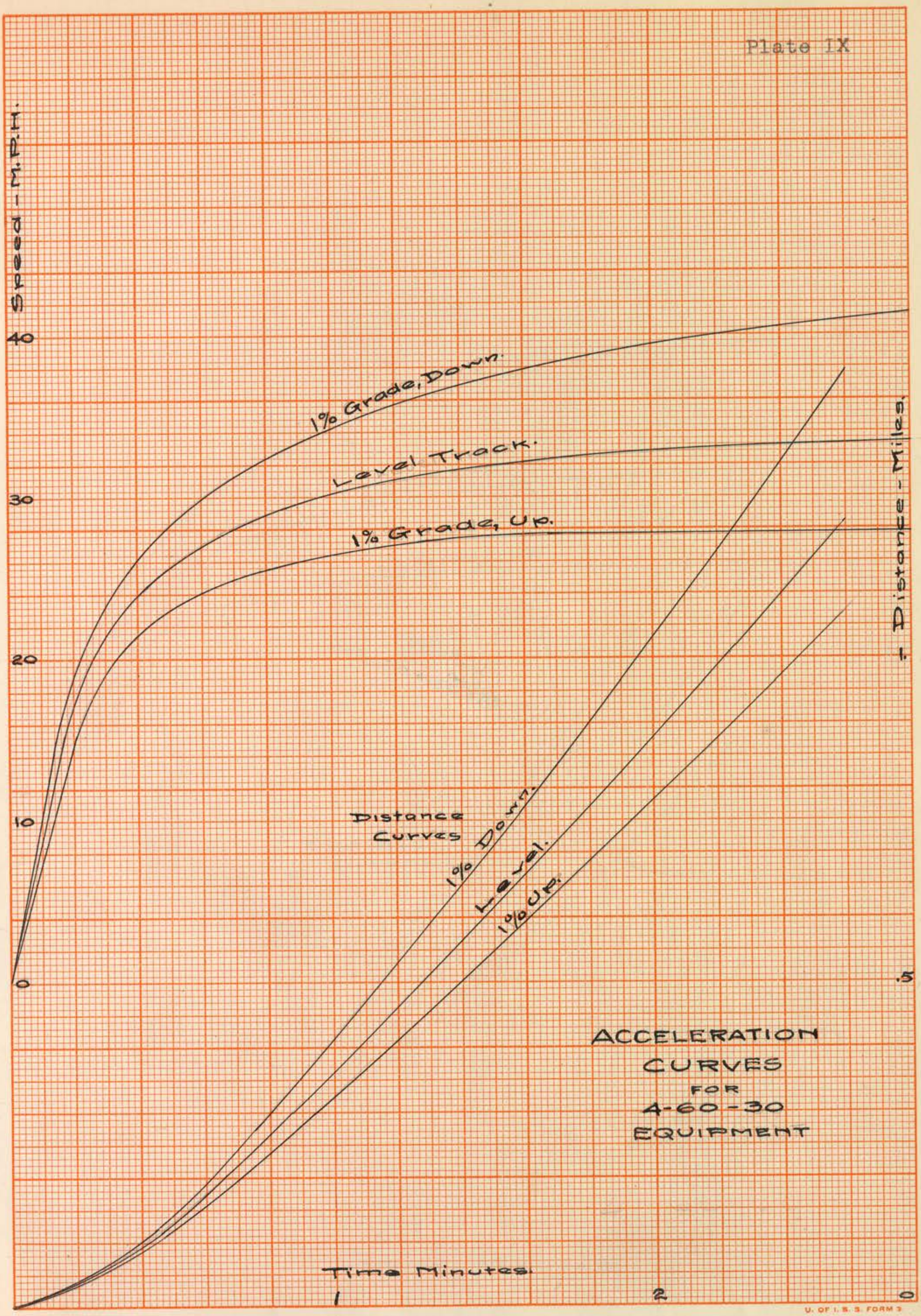
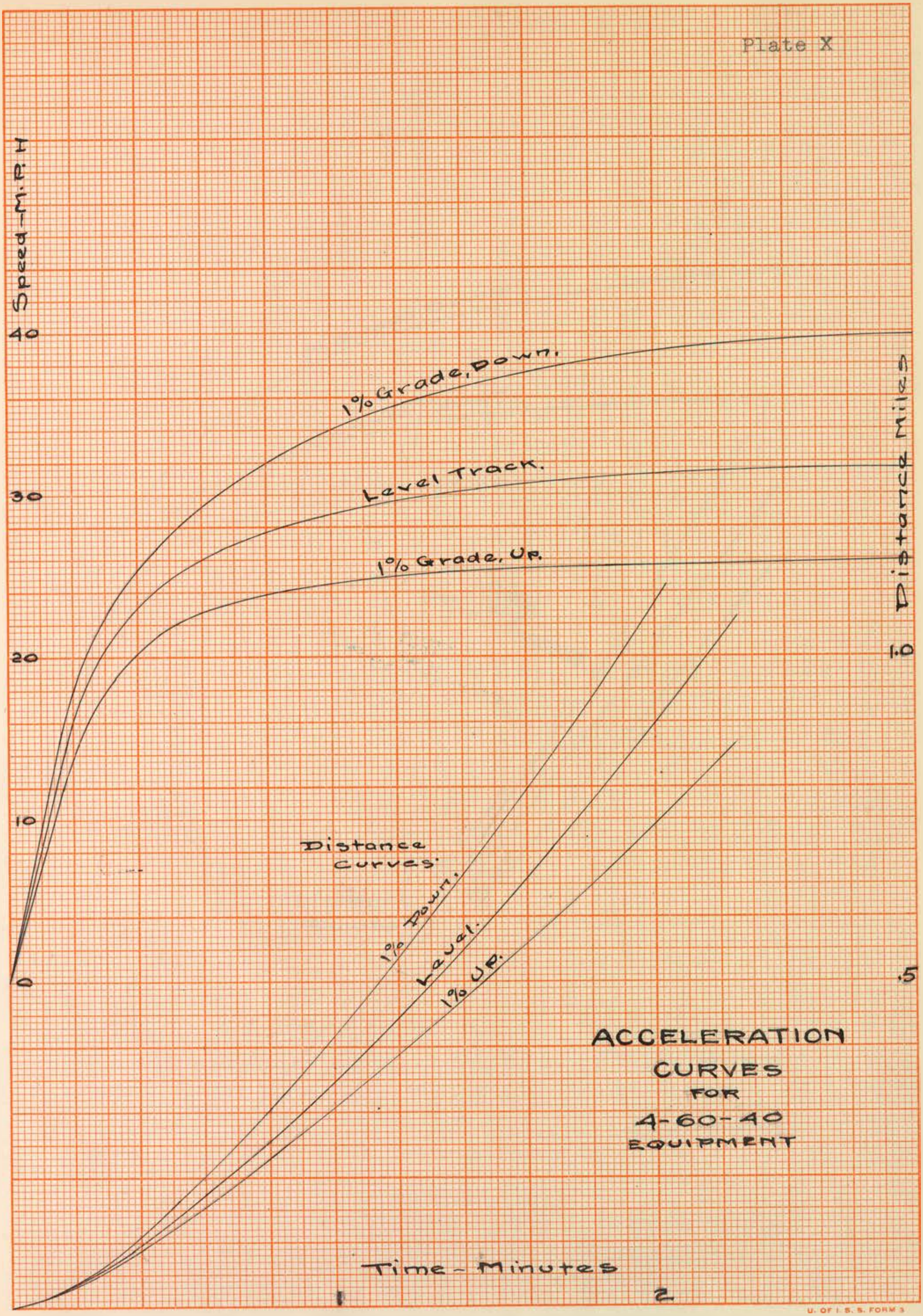
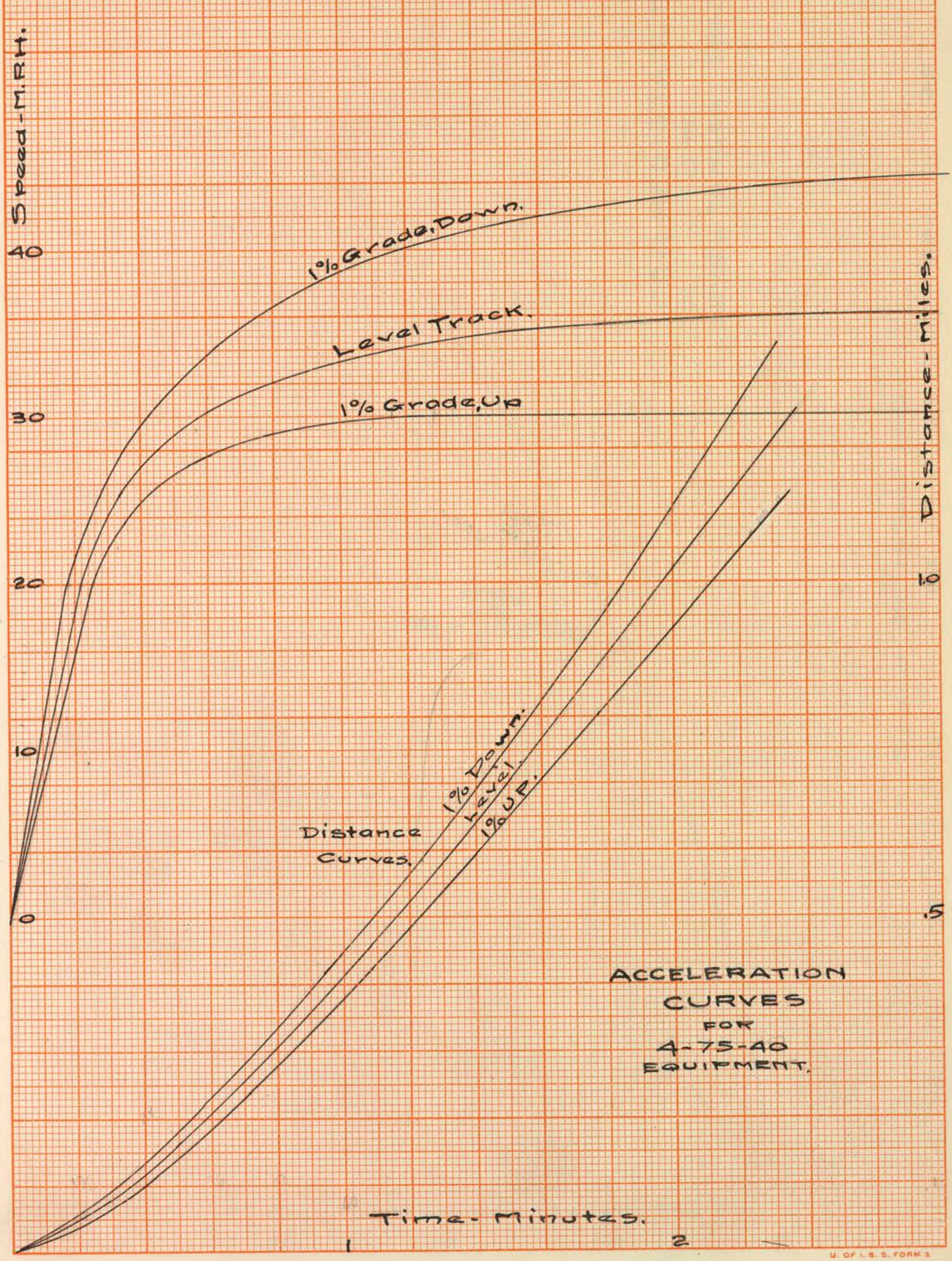

Speed - M.P.H.
40
30
20
10
0
1% Grade, Down.
Level Track.
1% Grade, Up.
Distance Curves
1% Down.
Level.
1% Up.
Distance - Miles.
1
.5
0
Time Minutes.
1
2
ACCELERATION
CURVES
FOR
4-60-30
EQUIPMENT
U. OF I. S. S. FORM 3

Plate X



U. OF I. S. S. FORM 3


Speed-M.P.H.
40
30
20
10
0
1% Grade, Down.
Level Track.
1% Grade, Up
Distance-miles.
1.0
.5
Distance
Curves.
1% Down.
Level.
1% UP.
ACCELERATION
CURVES
FOR
4-75-40
EQUIPMENT.
Time-Minutes.
1
2

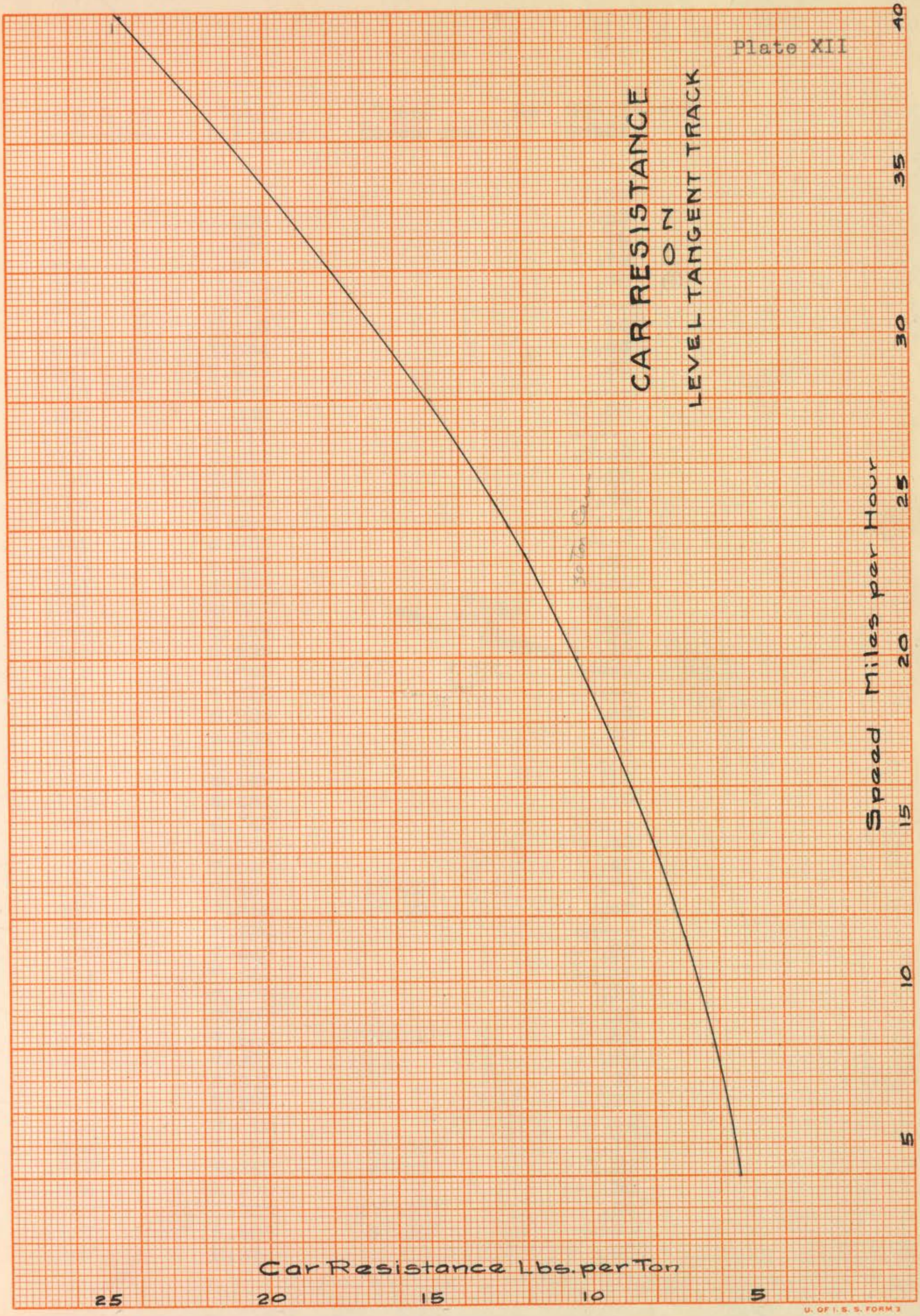

CAR RESISTANCE
ON
LEVEL TANGENT TRACK
Speed Miles per Hour
5
10
15
20
25
30
35
40
Car Resistance Lbs. per Ton
25
20
15
10
5
U. OF I. S. S. FORM 3

Plate XII

Length of Increment	Total Distance	Track Curvature	Net Equivalent Grade
.076			1.00
.132	.208		.50
.077	.285		- .50
.204	.489		- .70
.151	.678		.70
.189	.867		----
.143	1.010		1.00
.084	1.094		1.00
.341	1.435		.60
.132	1.567		----
.265	1.832		-1.00
.189	2.021		----
.079	2.100		-0.80
.189	2.381		.25
.284	2.665		- .85
.935	3.600		----
.435	4.035		-----
.204	4.237		.30
.341	4.579		- .50
.242	4.820		-----
.344	5.164		- .60
.466	5.630		- .10
.113	5.743	1^{o}	-----
.094	5.838		-----
.092	5.930		.40
.072	6.008		.40
.189	6.198		- .70
.151	6.349		- .20
.113	6.463	2^{o}	.10
.284	6.747		-----
.183	6.930		.40
.101	7.031		.40
.171	7.202	1^{o}-20'	- .70
.057	7.258	1^{o}-20'	.60
.076	7.334		-----
.113	7.448		- .85
.114	7.561		-----
.113	7.675		.33
.133	7.807		- .36
.076	7.883	1^{o}-00'	- .40
.038	7.921		- .50
.039	7.960		- .30
.037	7.997		- .30
.133	8.129		-----
.056	8.186	2^{o}-56'	1.13
.076	8.262	4^{o}-50'	1.22
.038	8.299		- .30
.062	8.362	20^{o}-00'	.60
.127	8.489	6^{o}-30'	-----
.047	8.536		.90

PLATE XIV

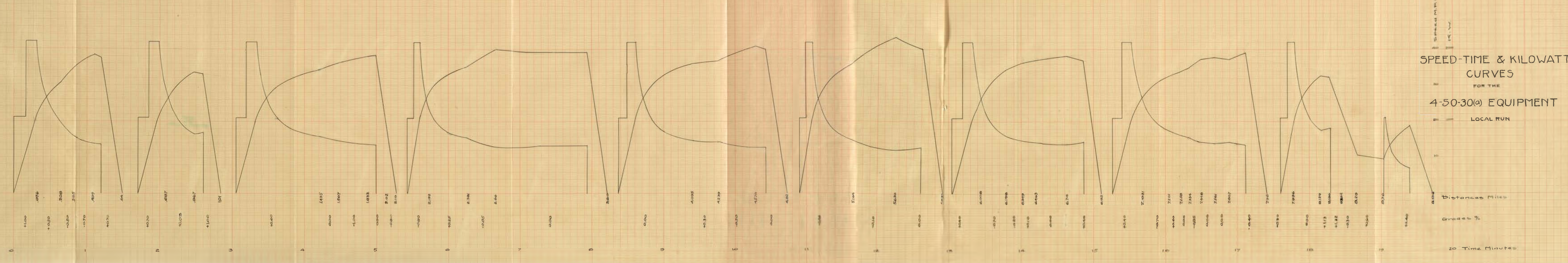
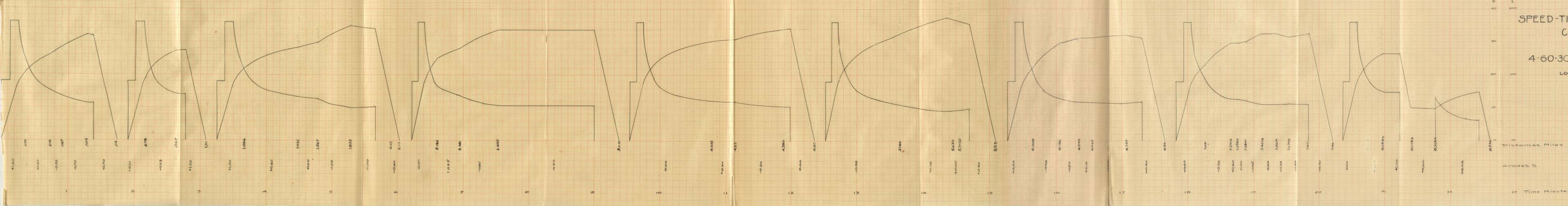

SPEED-TIME & KILOWATT CURVES
FOR THE
4-50-30(a) EQUIPMENT
LOCAL RUN
Distances Miles
Grades %
20 Time Minutes

PLATE XV

SPEED - TIME & KILOWATT
CURVES
FOR THE
4-50-30-(b) EQUIPMENT
LOCAL RUN



SPEED-TIME & KILOWATT CURVES

FOR THE

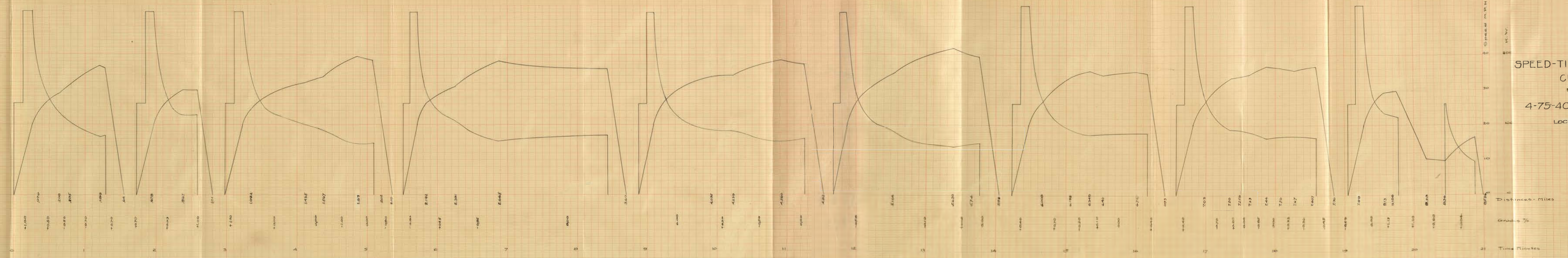
4-60-30 EQUIPMENT

LOCAL RUN

PLATE XVII


SPEED-TIME & KILOWATT
CURVES
FOR THE
4-60-40 EQUIPMENT
LOCAL RUN
Distances Miles
Grades %
Time Minutes

PLATE XVIII

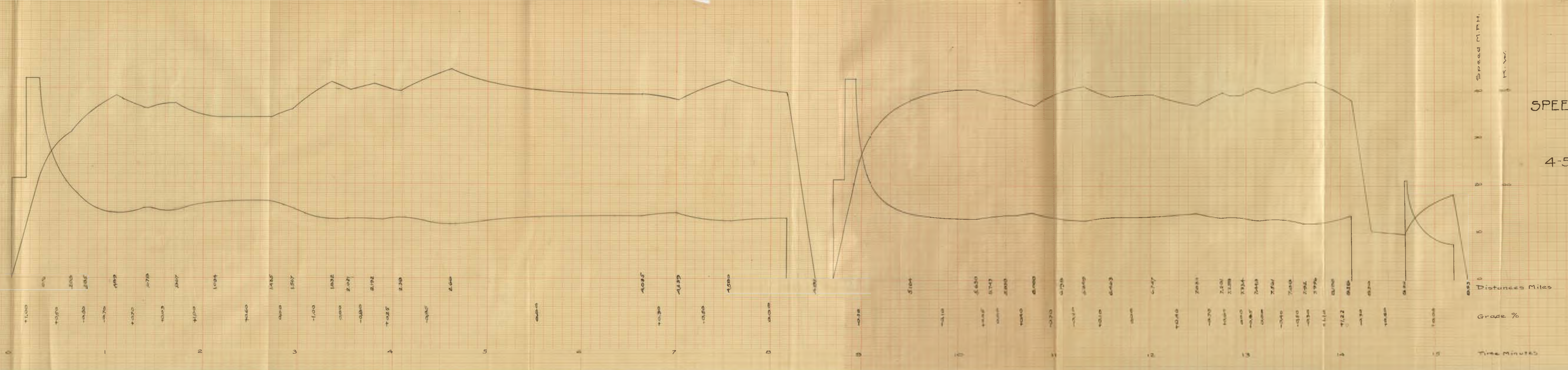


SPEED-TIME & KILOWATT CURVES

FOR THE

4-75-40 EQUIPMENT

LOCAL RUN



SPEED-TIME & KILOWATT
CURVES
FOR THE
4-50-30(A) EQUIPMENT
LIMITED RUN

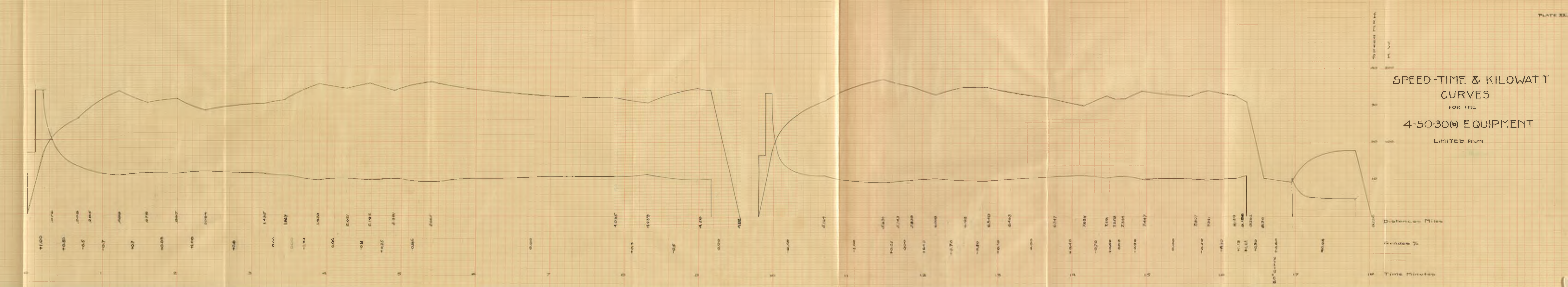
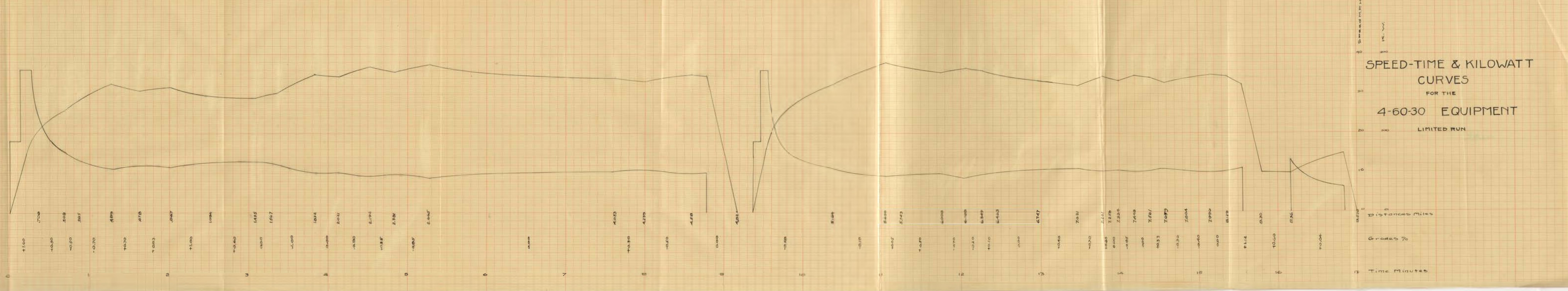


PLATE XX
SPEED-TIME & KILOWATT CURVES
FOR THE
4-50-30(b) EQUIPMENT
LIMITED RUN
Distances Miles
Grades %
Time Minutes

PLATE XXI


SPEED-TIME & KILOWATT
CURVES
FOR THE
4-60-30 EQUIPMENT
LIMITED RUN
40
200
30
20
100
10
Distances Miles
Grades %
Time Minutes
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17

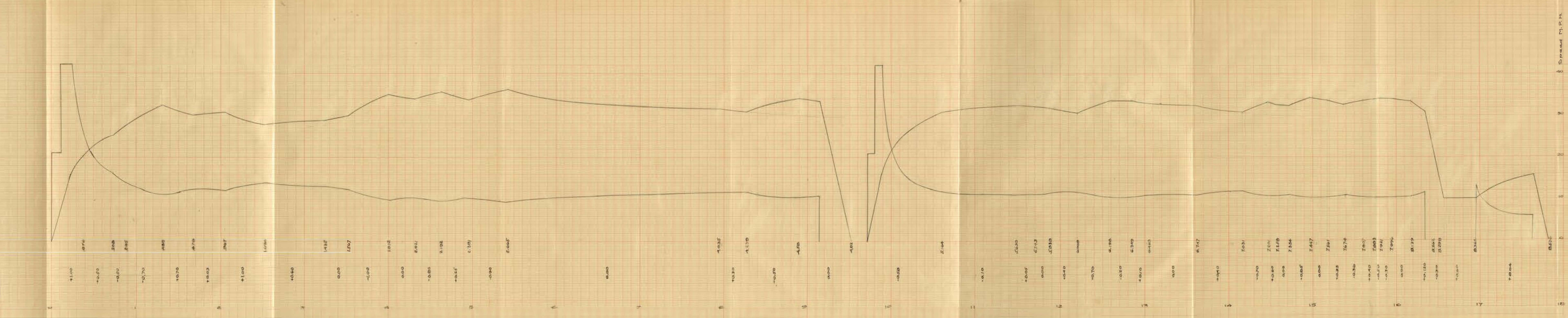
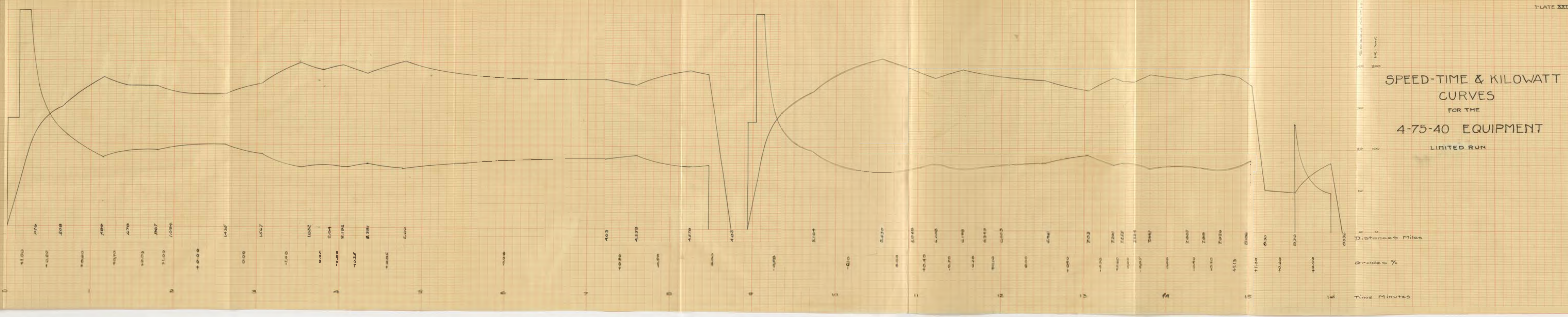

Speed M.P.H.

PLATE XXIII


SPEED-TIME & KILOWATT
CURVES
FOR THE
4-75-40 EQUIPMENT
LIMITED RUN
Distances Miles
Grades %
Time Minutes
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16